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GEOTHERMAL RESOURCES AND DEVELOPMENT IN THE REPUBLIC OF KOREA

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ABSTRACT

Geothermal in Korea is characterized by an absence of high-temperature resources for power generation. Hot springs are associated with localized, deeply-connected fracture systems mostly in granite areas. Geothermal utilization in Korea has, therefore, been of direct-use only, mainly in public baths with low-temperature geothermal water from a hundred wells hitting deeply-connected fractures. Recently a high heat flow anomaly was identified in the Tertiary sediment area in the south-eastern part of the Korean Peninsula The first low-temperature geothermal development project is currently being carried out at this location by the Korea Institute of Geoscience and Mineral Resources (KIGAM) for the purpose of district heating.

Geothermal heat pump installation is now booming; the number of installations and total produced energy approximately double annually. There are strong government subsidizing programs for fostering renewable energy and the total estimated subsidy for geothermal heat pump installations in 2006 reached US$11.8 million, twice that of the previous year.

One reason for the increasing number of geothermal heat pump installations is that the fluctuation in groundwater temperature and amount of extractable water varies little throughout the year. In Korea, for example, the amount of groundwater used for residence and industry in 2007 was 5.5 million m^3/day, which can be utilized for heating and cooling buildings nearby with groundwater-source heat pump system. The fact that it does not require any drilling cost when connecting heat pumps to existing groundwater well heads or pipe lines, offers great opportunity for expanding geothermal utilization. There are also several ongoing Research, Development and Demonstration (RD&D) works for utilizing thermal energy of alluvial groundwater in urban and suburban areas.

The fact that the thermal properties of subsurface such as thermal conductivity and volumetric heat capacity are the main factors controlling heat exchange rate in borehole heat exchanger was the motivator to initiate a nation-wide thermal property compiling program in which a total of 1,560 rock samples have been collected, measurements been done and then compiled into database system. First geothermal assessment ever tried in Korea has been recently made and the result shows that the total amount of heat down to 5 km beneath Korean territory reaches

10^5 EJ which corresponds to ten thousand times the annual primary energy consumption.

1. INTRODUCTION

It is well known that the geothermal resources in Korea are characterized by absence of high-temperature resources for power generation, and hot springs are associated with localized, deeply-connected fracture systems mostly in granite areas. Recently we identified a geothermal anomaly in terms of high heat flow and geothermal gradient at the Tertiary sediment area in the south-eastern part of the Korean Peninsula, where the low-temperature geothermal development program is currently being carried out by the Korea Institute of Geoscience and Mineral Resources (KIGAM). The recently updated heat flow map shows a geothermal anomaly exists along a big fault system in south eastern part of Korean Peninsula and extends to this Tertiary sediment area.

Although there is no district heating application of geothermal energy, geothermal heat pump installation is booming thanks to a strong government fostering program. Groundwater thermal energy utilization is a promising area in that we can reduce or waive initial costs for installing a borehole exchanger network and several demonstration works produced successful results. Since accurate information on thermal properties of subsurface material is critical in designing optimum borehole heat exchanger network, a nation-wide sampling and thermal property measuring program has been launched, to compile a database of thermal properties of 1,560 rock samples.

In this paper, we briefly summarize the national policy on renewable energy and show recent statistics on renewable energy consumption and geothermal uses as well. Characteristics of geothermal resources in Korea are briefly discussed with recently updated heat flow and hear production maps. The first geothermal assessment in Korea is also mentioned. Results of some recent R&D programs are introduced with emphasis on those achievements or problems. Finally, we discuss overall current status and outlook of geothermal development in Korea.

2. NATIONAL POLICY AND STASTICS OF RENEWABLE ENERGY

The Korean Government does not have an independent strategy for geothermal yet, but ‘new and renewable energy policy’. In 2000, the government established the foundation for certification research and performance analysis with an aim to promote the use of renewable energy. The development of Korean ‘new and renewable systems’ began by focusing investment on the technology and development in three selected areas with big market potential; photovoltaic, wind power and fuel cell. The “Second Basic Plan for the Development, Use and Supply of New and Renewable Energy Technology (2003~2012)” was established in 2003 along with detailed promotional plans for the annual development and supply of new and renewable energy sources to achieve the goal of increasing the use of new and renewable energy to 3% of the total primary energy consumption by 2006 and 5% by 2011.

The total use of new and renewable energy at the end of 2006 reached 5.26 million ton of oil equivalent (TOE) accounting for only 2.26% of the total primary energy consumption (see Figure 1); the goal of achieving 3% has not yet been accomplished and it does not seems effortless to achieve the goal of increasing the renewable energy’s share to 5% by 2011 without a special activating plan which will be prepared in 2008. Note that the renewable energy in Korea includes waste and large hydropower as well as commonly used items such as photovoltaic, solar, wind, bio, small hydro and geothermal. Therefore, if we account only for renewable energies defined by International Energy Agency (IEA), then the renewables’ share in 2006 is far less than 1.0 % (Figure 2).

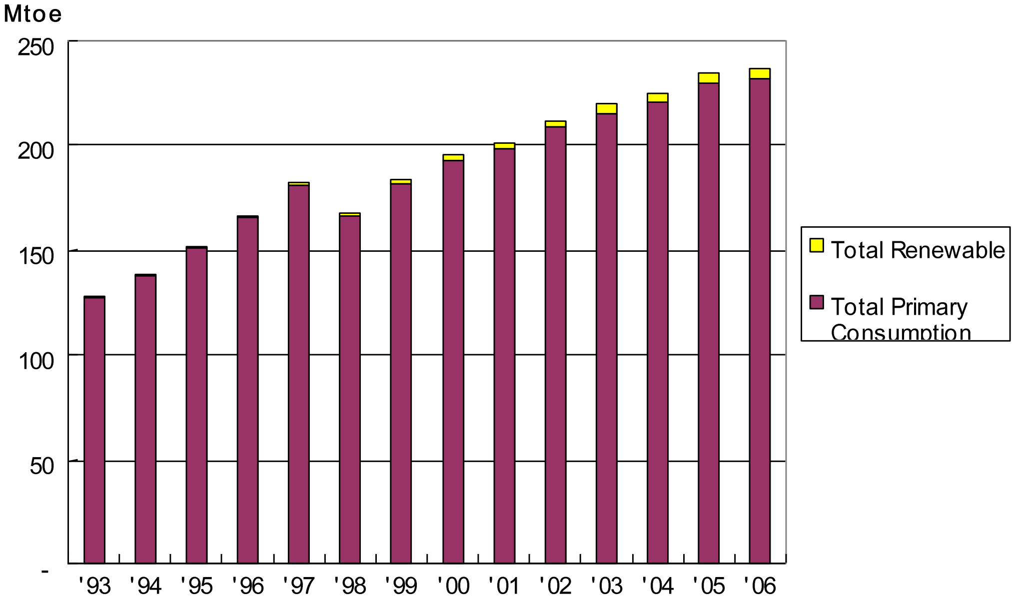

FIGURE 1: Trend of primary energy and renewable energy consumption in Korea.

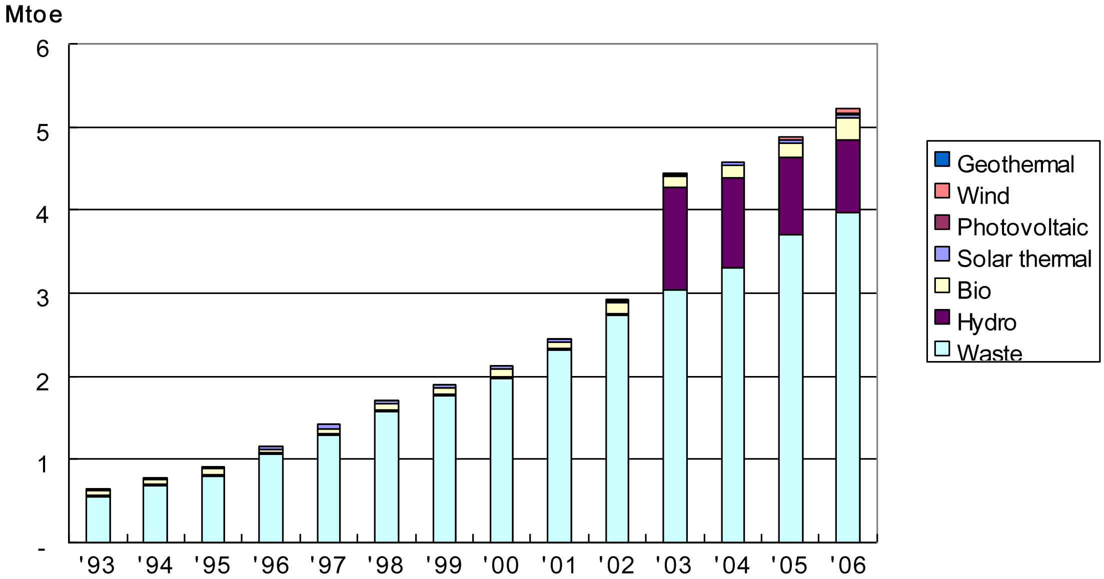

FIGURE 2: Increase of renewable energy consumption in Korea. Note that from 2003 large hydro came into category of renewables.

3. INCREASING GEOTHERMAL USES

Status and prospect of geothermal energy still does not seem significant because the government program focuses on the three major as areas within renewable energy; photovoltaic, wind power and fuel cell. Fortunately, however, the importance of geothermal utilization is being acknowledged by the government and the public stimulating the incentive for geothermal and the market share is rapidly increasing. Therefore, we expect that remarkable progress can be made in the next five years.

Geothermal utilization in Korea has been of direct-use, mainly in public baths with low-temperature geothermal water from a hundred wells hitting deeply-connected fractures. There is no district heating using geothermal energy, but the low-temperature geothermal development program is on-going in the Pohang area in the south-eastern part of Korea, where high heat flow and geothermal gradient are identified. The current status of geothermal energy direct-use is summarized in Table 1 as of December 31, 2006.

TABLE 1: Geothermal energy direct-use in Korea as of December 31, 2006.

Use	**Installed Capacity (MWt)**	**Annual Energy Use (TJ/yr=10^{12} J/yr)**	**Capacity Factor**
Bathing and Swimming	13.53	163.29	0.38
Geothermal Heat Pumps	53.86	260.74	0.15
Total	67.39	424.03	

Increases of geothermal heat pump installation and energy uses are manifested in Table 2. Note that the values are based on the officially reported installations and we expect that the actual number of installations is much bigger than reported, and we can acknowledge that geothermal heat pump installations are now booming; the number of installations and total produced energy approximately double annually, which is mainly due to strong government subsidizing programs for fostering renewable energy. The Korean Government offers long-term low-interest loans, tax benefits and government/public funds for those using renewable energy. Subsidy for geothermal installation through various renewable energy deployment programs amounted to US$ 11.8 million in 2006 (see Table 3). Also from 2004, the ‘Mandatory Public Renewable Energy Use Act’ has come into effect stating that “in construction of all public buildings bigger than 3,000 m^2 in area, more than 5 % of total budget must be used to install renewable energy equipments.” Geothermal heat pump installation is now being accelerated with this act.

TABLE 2: Increase of geothermal heat pump installation during the last five years (KEMCO, 2007)

	2002	**2003**	**2004**	**2005**	**2006**
Installed Capacity (MW)	0.74	2.39	6.31	8.32	35.7
Annual Energy Used (GWh)	1.44	4.64	16.0	30.2	73.3

TABLE 3: Government subsidies for geothermal heat pump installation deployment as a market stimulation incentive (KEMCO, 2007).

	2004		**2005**		**2006**	
	Capacity (MW)	Subsidy (1,000 USD)	Capacity (MW)	Subsidy (1,000 USD)	Capacity (MW)	Subsidy (1,000 USD)
Deployment Program	2.83	1,886	5.92	3,642	16.94	9,541
Rural Deployment Program	1.44	1,505	1.82	1,770	2.57	2,252
Total	4.27	3,391	7.74	5,412	19.51	11,793

Borehole heat exchanger systems have played a major role in the increase of geothermal heat pump installations. Recently, however, groundwater thermal energy utilization attracts attention in that temperature and the amount of groundwater from many existing wells vary little throughout the year. In Korea, for example, the amount of groundwater use for residence and industry reaches up to 5.5 million m^3/day (MOCT, 2007) that can produce a huge amount of thermal energy for heating and cooling buildings nearby. The fact that it does not require any drilling cost when connecting heat pumps to existing groundwater well heads or pipe lines, offers great opportunity of expanding geothermal utilization. There are also several ongoing RD&D works for utilizing thermal energy of alluvial groundwater in urban and suburban areas.

4. CHARACTERISTICS OF GEOTHERMAL RESOURCES IN KOREA

It is well known that the geothermal resources in Korea are characterized by absence of high-temperature resources for power generation and hot springs are associated with localized, deeply-connected fracture system mostly in granite area. The geology of Korea is composed of relatively old rocks such as Precambrian metamorphic rocks, Paleozoic and Mesozoic sedimentary rocks, Jurassic and Cretaceous granites, and some of volcanic rocks.

Figure 3 shows the terrestrial heat flow map of Korea with sample locations. A total of 359 heat flow data points of in-land Korea is presently available. Among them, 35 data points have been measured in the 1970's and 213 data points were collected until 1997 by KIGAM researchers. During the years 2004 and 2005, another 111 data points have been collected in the area close to the deep boreholes where geothermal gradient measurements had been made. We measured the thermal conductivity at the data site to compile an updated heat flow map of Korea. The weighted average of heat flow values over Korea with an areal window of 500 m by 500 m is 60±11 mW/m^2.

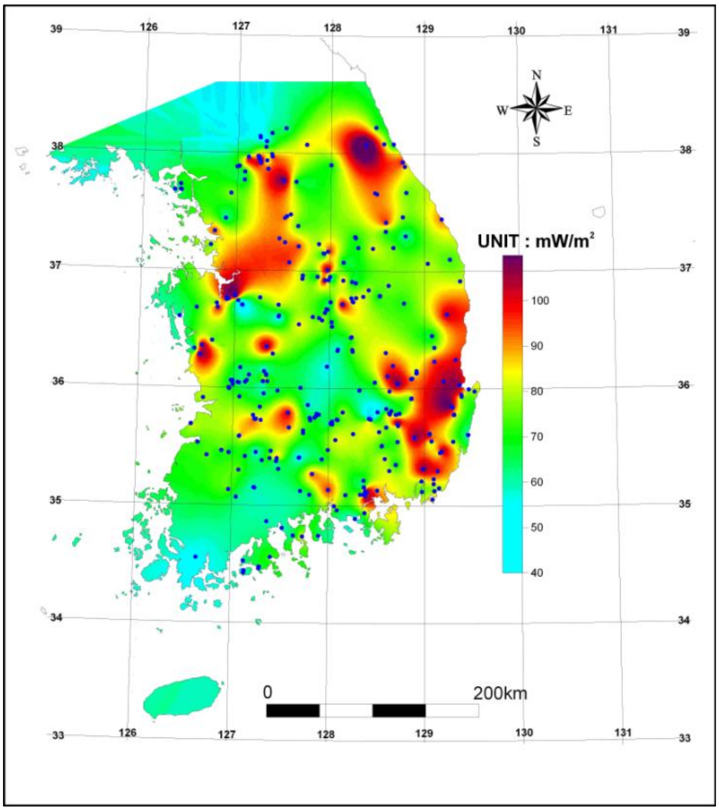

FIGURE 3: Heat flow map of Korea with 359 samples (marked with dots).

Figure 3 shows that the location of data points is still insufficient to cover the whole territory with regular spacing. Also high heat flow anomalies generally coincide with the location of hot springs, especially some isolated ones. These anomalous features come from the localized convection of hot water due to pumping for spas although we did not include the pumping wells themselves, and thus those are not to be considered as true heat flow anomalies. A regional high heat flow anomaly is found along the famous Yangsan Fault in the south-eastern part of Korea; which imposes that the Yangsan Fault adjacent to the Milyang, Moryang and Dongrae Faults may work as a regional convection belt through tectonic activities. The north-eastern extension of this high heat-flow anomaly coincides with the only area covered with Tertiary sediments, in which the Pohang low-temperature geothermal development site is located.

The study of heat production rates in Korea is especially interesting, because the geology of Korea mainly consists of gneiss and granite. Recently, KIGAM compiled a heat production map using 180 samples throughout the territory: chemical analyses of 125 rock samples and interpretation of 55 gamma-ray logs in crystalline formation (Figure 4). Average heat production rates of granite (132 samples) and gneiss (48 samples) are 2.040±0.086 $\mu W/m^3$ and 2.041±0.162 $\mu W/m^3$, respectively. The heat production rate of the granite in Korea is lower than usual values (average of 3.0 $\mu W/m^3$) reported in Cermak and Rybach (1982) and when comparing Figure 4 with heat flow map shown in Figure 3 we cannot see a clear correlation between spatial distribution of heat production and heat flow. This is mainly due to the relatively old age and surface exposure of the rocks.

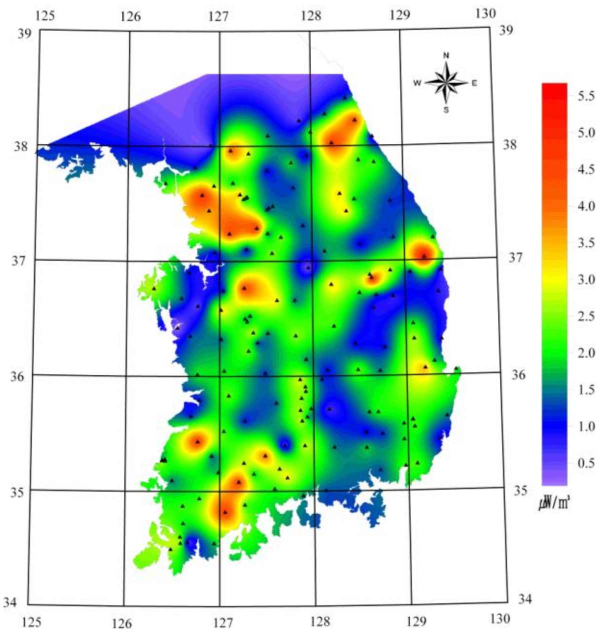

FIGURE 4: Heat production map of Korea with 180 samples marked with triangles (unit: $\mu W/m^3$).

FIGURE 5: Location map of 1,560 rock samples for measuring density, specific heat and thermal conductivity.

In addition to heat flow and heat production data, recent compilation of density, thermal conductivity and specific heat measurements with 1,560 rock samples (Figure 5) and surface temperature data has led to an update of the temperature distribution map various depths. Finally, the first geothermal assessment in Korea can be provided by the following formulae;

Temperature at depth *z*: $$T(z) = \frac{A_0 b^2}{\lambda}(1 - e^{-z/b}) + \frac{Q_0 - A_0 b}{\lambda} z + T_0$$

Heat contents down to depth *z*: $Q = \rho C_p V \;\; T(z) - T_0$,

Where T_0 is surface temperature, Q_0 the surface heat flow, A_0 the heat production, V the total volume in the depth interval, ρ the density, C_p the specific heat, λ the thermal conductivity and b the attenuation depth. Thus estimated heat content in Korean territory down to 5 km reaches some 10^5 EJ (Lee et al. 2007). That is approximately 10,000 times the primary energy consumption in 2006. This estimate is based on volumetric methods and practically available resources are fewer considering the available fluid contents with the viable technologies of today. The estimate is important as the first quantitative geothermal assessment in Korea.

5. MAJOR RECENT R&D AND RD&D EFFORTS

5.1. Pohang low-temperature geothermal development program

KIGAM started the Pohang project to develop geothermal water for district heating and agricultural application in the area showing high geothermal anomaly, north of Pohang city in the south-eastern part of Korea, in 2003. The target area was selected first by the geothermal anomaly shown from heat flow and geothermal gradient maps. Hereafter, lineament distribution analysis using Landsat image and structural geological mapping was applied to find possible deep fractures that would work as geothermal water conduits. The area belongs to the Tertiary Pohang Basin overlying Cretaceous sedimentary rocks, Eocene volcanic rocks such as tuff and Permian grano-diorite basement. The Pohang Basin consists of Miocene marine sediments and bottommost clastic sediments layer. The Heunghae basin, the main target of the geothermal exploration, is covered with Quaternary alluvium underlain by these thick Tertiary sediments with relatively low thermal conductivity and thus preserving high geothermal gradient, which is quite uncommon in Korea.

Numerous geophysical survey methods have been applied such as gravity and magnetic surveys for interpretation of the regional geologic setting, magnetotelluric (MT) and controlled-source audio-frequency magnetotelluric (CSAMT) surveys for mapping the resistivity structure and possible fracture zones, and self-potential survey for examining hydrologic condition associated with geothermal flow. Drilling of two pilot wells 165 m apart, one is a rotary well and the other is a coring borehole, started in August 2003 to confirm the existence of the geothermal reservoir. The rotary well went down to 1.5 km and the coring borehole to 1.1 km. The drilling results showed a geothermal gradient of 40 °C/km and existence of several permeable zones related with fracture systems.

After finishing the pilot wells, pumping tests along with monitoring of self-potential over the area, draw-down at the adjacent well, and chemical components of pumped water have been performed to confirm that there exist several permeable zones associated with deep fractures. A three-dimensional imaging of subsurface structures using MT data has been made and it was identified that the fracture zone extended down to at least 2 km in depth. Based on these results, another well has been drilled down to 2.383 km to find basement at depth of 2.265 km at the end of 2006. Several geophysical loggings were performed only down to less than 2 km due to instruments durability against high pressure and temperature at its bottom. Drilling and geophysical logs, however, indicated that there are several permeable zones, where considerable amounts of leakage of the drilling mud and abrupt change in temperature profile was observed. The temperature was 82.5 °C at 1.98 km and is expected to be over 90 °C at 2.3 km depth.

There are still various problems in the well, such as incomplete well casing, partial collapse in uncased depth interval, remaining mud cakes in permeable zones, etc. Furthermore, bottom-hole temperature has not yet been monitored and preliminary pumping was not satisfactory. All of these problems have resulted from lack of experience in deep drilling in a large diameter well (deeper than 1.5 km).

Trouble shooting for the well is now being performed and afterwards the characterization of the geothermal reservoir will be performed, including pumping test, chemical analysis of pumped waters, various borehole surveys, etc. Once the results are successful, then practical utilization of the geothermal water is to follow; for example, a doublet system including one injection well would be considered for the various applications including space heating, green house, aquaculture, and so forth.

5.2. Geothermal heat pump system with alluvial groundwater

Annual groundwater use in Korea amounted to 3.75 billion m^3 in 2006 (MOCT, 2007), 54% of which is for residence and industry use (approximately 5.5 million m^3/day). The fact that it does not require any drilling cost when connecting heat pumps to existing groundwater well heads or pipe lines and that the temperature of groundwater varies little throughout the year, offers a great opportunity for expanding geothermal utilization. Groundwater in crystalline rocks flows through fractures and thus it is not easy to find or tap groundwater in regions other than alluvial areas in Korea. In alluvial areas, on the other hand, relatively sufficient amount of groundwater is ready for use for agriculture, living, industry and even for municipal water supply system.

One of the major recent cases of groundwater thermal energy utilization is the installation of the heat pump directly connected to the municipal water supply pipe line from a bank infiltration system. There are several pumping wells along the Nakdong River, south-eastern part of Korea, utilizing bank infiltration system to supply portable water to a big town, Changwon City. The maximum capacity of the system is to supply a total of 180,000 m^3/day with 24 pumping wells while the amount of 60,000 m^3/day is pumped, processed and supplied at the moment. The purpose of the application was to demonstrate a way of utilizing the huge amount of thermal energy contained in the infiltrated groundwater. Since it is a demonstration or proof-of-concept installation, a small size heat pump with a capacity of 52.8 kW was installed to supply heat and cooling of a room with an area of 145 m^2 in a three-story office building. We made a by-pass at the main pipe line from a well with a capacity of 2,000 m^3/day to the heat exchanger of the heat pump system. The temperature of the pumped water is 17 - 18 °C throughout the year and flow rate to the heat pump is 4 - 5.5 m^3/hr depending on heating or cooling load. In test operation, the coefficient of performance (COP) of heat pumps for heating showed values higher than 3.7 while system COP was higher than 3.4, to confirm its high efficiency.

Another example is a heat pump system using drained groundwater underneath a building. In alluvial areas, there is substantial amount of effluent groundwater to be drained from the initial stage of building construction. The amount of groundwater changes depending on rainfall but in many cases the minimum amount is still enough to extract thermal energy for heating and cooling purposes. A proof-of-concept installation of two heat pump systems with a capacity of 12.3 kW was made in separated rooms of a church building; one with the submerging heat exchanger in water tank and the other with open-loop type. Both systems show fairly high COP; the maximum heat pump COP being 5.7 while overall system COP being 4.1 with open loop type.

The performance of the systems is continuously being monitored and we expect this to be an important corner stone of expanding geothermal heat pump installation especially by utilizing groundwater thermal energy.

5.3. Compiling thermal property database

Rapid increase of geothermal heat pump installation is mainly due to a strong government subsidizing program. Although the installation of groundwater-source heat pumps is increasing its proportion, most of the heat pump systems so far are based on borehole heat exchanger system. In the year 2005, KIGAM initiated a government funded R&D program for compiling a map of thermal properties of subsurface materials throughout its territory to provide basic design parameters to geothermal heat pump installers. Although geothermal heat pump installation in Korea is booming, quantitative information on the thermal properties of subsurface materials has not been provided yet. As a consequence, installed heat pump systems are likely to be over-designed, which can make the systems less competitive in terms of initial cost.

By the end of 2007, a total of 1,560 rock samples have been collected as shown in Figure 5. Density, specific heat and thermal conductivity, or otherwise thermal diffusivity of each rock sample has been measured and compiled into a database. Figure 6 shows the distribution of thermal diffusivity and thermal conductivity values of igneous, metamorphic and sedimentary rocks as box diagram. The database will be open on the website along with temperature distribution on the ground surface and at each depth slices in a 1:250,000 scale geologic map to help geothermal heat pump designers and installers using those data as input parameters in designing an optimum borehole heat exchanger system.

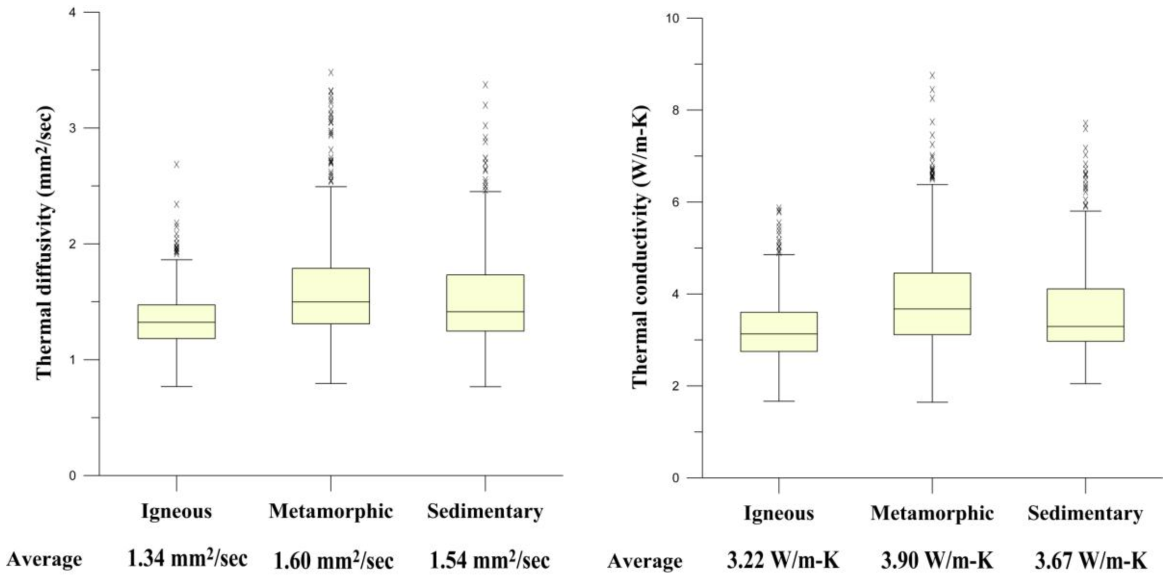

FIGURE 6: Distribution of thermal diffusivity and thermal conductivity measurements of 1,560 rock samples (Park et al., 2008).

6. DISCUSSION AND CONCLUSIONS

Although some measurements of heat flow had been performed with a few rock samples from the 1970's and there have been continuous measurements of geothermal gradients along wells deeper than 300 m for the purpose of hot spring investigation, it was not until Pohang low-temperature geothermal project started in 2003 that a systematic study on the geothermal characteristics and the development of direct-use geothermal resources initiated. For the past five years, a notable progress has been made; for example, geothermal gradient map and heat flow maps have been updated to represent geothermal characteristics and interpretation of heat flow distribution in terms of geology, age of formation and rock type has been made (Kim and Lee, 2007) as well. As a result, we came to find that geothermal phenomena such as hot springs in Korea have little to do with anomalous region in terms of heat flow, but rather are related with deeply extended fracture system in crystalline rock formation. Continuous efforts to collect rock samples and to measure the thermal properties have led to thermal property database compilation and also to the first geothermal assessment in Korea.

District heating with geothermal energy in Korea has not been realized because the Pohang project, the first low-temperature geothermal development program in Korea, has not produced successful results yet. Due to lack of experience in deep drilling and in engineering through deep wells and other technical problems, the project schedule has been delayed several times and we plan to finish the well completion by the end of 2008. Once we can see successful results from pumping tests and reservoir characterization, supply systems to nearby apartments will be designed to realize the first geothermal district heating case.

Installation of geothermal heat pumps is a promising area in Korea ubiquitous geothermal energy can be tapped regardless of rock type and geothermal characteristics. Tthe climate of Korea makes people need heating in winter and cooling in summer and thus high capacity factor is expected. However, drilling cost for installing borehole heat exchanger networks is still a weak point in an economic sense. In that point of view, heat pump using thermal energy of groundwater offers an emerging market since we can reduce the initial cost by a considerable amount. Successful results from the cases using groundwater thermal energy has led to launching other proof-of-concept R&D programs on alluvial groundwater thermal energy and aquifer thermal storage. Considering dense population especially in urban and suburban area most of which lies along river, we expect geothermal heat pump installation using alluvial water will continuously increase. Considering some successful results and increasing RD&D activities thanks to strong government support, direct-use geothermal development in Korea will continue to be active at least for the next five years and we expect the geothermal utilization in Korea to contribute to world-wide statistics to some extent by 2010.

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